Benefits of Stormwater Management: Improved Water Quality

Contents

Overview

Contaminants from stormwater runoff are a major source of surface water pollution. Stormwater can contribute significant amounts of sediment and suspended solids, nutrients, heavy metals, pesticides, bacteria, and industrial by-products to watersheds and beaches. These contaminants can contribute to severe habitat degradation in streams by depleting oxygen and reducing water clarity, and can also accumulate in fish and other animal tissues leading to wildlife disease and mortality as well as risks to human health. Numerous studies have shown that as urban development increases, water quality and biodiversity decrease in surrounding watersheds. These factors can lead to a loss of valuable ecosystem services.

Low-impact development, best management practices, conservation, and restoration can all be applied as effective tools for stormwater management. These strategies can reduce the amount of pollutants and contaminants in runoff, preserve habitat in rural areas and create habitat in urban areas, and restore ecosystem services such as flood attenuation, natural water filtration, and soil retention. The research summaries included below describe these services in detail and also demonstrate the benefits of stormwater management for water quality. Many of these benefits can be quantified and translated into economic values. The first section describes studies containing monetized benefits. The remaining sections include studies that illustrate ecological benefits of improved water quality.

Supporting Research

Monetized Benefits

Assessment of costs and benefits of three stormwater management alternatives yields low benefit-cost ratios. Los Angeles, CA. Kalman et al. 2000

- Evaluated the costs and benefits of three stormwater treatment alternatives (implemented as retrofits) for the Ballona Creek watershed in Los Angeles County, CA.
  - Detention with screening, which provides aesthetic improvement and reduction in mass loading of debris and total suspended solids (TSS). Cost: $168,166,000, Benefit: $1,492,000, B/C Ratio: 0.0089.
  - Filtration with disinfection, which reduces fecal coliform concentrations and provides improvements in stormwater quality to meet recreational use standards. Cost: $262,170,000, Benefit: $1,613,000 B/C Ratio: $0.0062.
  - Advanced treatment by reverse osmosis, which reduces dissolved metals and toxics concentrations and improves stormwater quality to meet all receiving water objectives. Cost: $418,672,000 Benefit: $1,644,000, C/B Ratio: 0.0040.
- To be economically viable, other management alternatives would have to retain similar benefits but be several orders of magnitude less expensive.
- An analysis of treatment of state highway runoff in the Ballona Creek basin using the three levels of treatment listed above compared to basin-wide treatment showed that basin-wide treatment is much more cost effective than one polluter treating alone.

Low impact development management approaches can offer significant water quality, habitat, and wetland benefits valued at more than $300 million over a 40-year planning period. Philadelphia, PA. Raucher 2009

- Evaluated willingness to pay for improvements to water quality, habitat improvements, and wetland creation and enhancement associated with a management option in which 50% of runoff from impervious surfaces is managed through green infrastructure (the 50% LID option).
- Separately evaluated WTP for households within Philadelphia and nearby households outside of the City due to differences in demographics and location.
- The 50% LID option yielded an estimated annual willingness to pay of approximately $10 to $15 per household per year if the water quality and related habitat enhancements are fully realized or $330 million over the 40-year analysis period (2010 to 2049).
- LID-related watershed restoration and related efforts are expected to create or enhance over 190 acres of wetlands. For the 50% LID option, these added wetland acres and related services are estimated to provide more than $1.6 million in added value city-wide, in present value terms, over the 40-year project planning period.

Batstone et al. (2010) **use a choice experiment to determine public WTP for coastal water quality; applies to cost of water quality project. (New Zealand)**

- Willingness to pay for increased water quality and ecological function of coastal waters/beaches shows value in stormwater treatment project
- Estimates value of water quality improvement project from WTP at between $783 million and $1.1 billion (NZ $)

The Trust for Public Land's Center for City Park Excellence for the City and County of Denver (2010) **presents the economic benefits of Denver's park and recreation system.**

- By considering the rainfall, parkland, imperviousness and treatment cost factors, the authors obtained a total annual Stormwater Retention Value for the park system of Denver. (see figure 1 below)
- The trees and soil of Denver's parks retain rainfall and cut the cost of treating stormwater values at just under $804,000; park trees and shrubs absorb a variety of air pollutants valued at nearly $129,000

Table 6. Stormwater Cost Savings Due to Parks in Denver

Typical Year	Inches	Cubic Feet
Rainfall	15.65	357,104,517
Runoff with parks		24,413,590
Runoff without parks		102,489,990
Runoff reduction due to parks		78,076,400
Runoff reduction rate	76%	
Cost of treating stormwater ($ per cubic foot)		$0.0103
Total savings due to park runoff reduction		**$804,187**

Figure 1 Stormwater Cost Savings Due to Parks in Denver (Trust for Public Land 2010)

Improved Habitat and Biodiversity

Armstrong et al. (2010) **conducted a study using field sampling and statistical analysis (GLM) to determine human impacts on fish in MA streams.**

- Study examines impacts of anthropogenic land use changes on fish communities; both flow alteration and impervious cover impacted fish populations (richness and abundance)
- Impervious cover and flow alteration both were demonstrated to influence fish communities; quantile regression indicated that flow alteration and impervious cover were negatively associated with both fluvial-fish relative abundance and fluvial-fish species richness
- Findings show that a one-unit (1%) increase in the percent depletion or percent surcharging of August median flow would result in a 0.4-percent decrease in the relative abundance (in counts

per hour) of fluvial fish and that the relative abundance of fluvial fish was expected to be about 55 percent lower in net-depleted streams than in net-surcharged streams.

- The GLM models also indicated that a unit increase in impervious cover resulted in a 5.5-percent decrease in the relative abundance of fluvial fish and a 2.5-percent decrease in fluvial-fish species richness.

Brand and Snodgrass (2009) **conducted a survey of amphibian breeding habits at stormwater pond sites compared to other waterbodies.**

- In urban and suburban landscapes with naturally low densities of wetlands, wetlands created by current or historic land uses may be as important to amphibian conservation as natural wetlands or pools; however some ponds may have high levels of pollutants and become ecological traps
- In suburban watersheds most (89%) of the wetlands that had breeding activity were either stormwater ponds or otherwise artificial.
- This pattern was also evident in the forested watersheds, where amphibians were primarily found breeding in wetlands created by past human activity.
- Late-stage larvae were found only in anthropogenic wetlands in all study areas because the remaining natural wetlands did not hold water long enough for larvae to complete development.
- Study suggests that ponds could be managed on a landscape scale so that those ponds most likely to be colonized by amphibians are prioritized and designed to best aid amphibian reproductive success, while other ponds are created strictly for pollutant or hydrology management.

Green roofs create habitat that supports urban biodiversity. Berlin and London. Wise et al. 2010

- Reviews several studies that have documented the ability of green roofs to support biodiversity and provide valuable habitat for a variety of flora and fauna:
    - A study of vegetated roofs in Berlin (Köhler 2006) found plant species diversity representing close to seven percent of the species present in the region.
    - A study of green roofs in the Greater London area (Kadas 2006) found that at least 10% of the fauna species identified on the roof were classified as “nationally rare and scarce.” The author identified spider species representing 30% of the region’s known spider species.
- The heterogeneity of habitat exposures and roof surfaces (e.g., sunny/shady; moist/dry) is an important parameter influencing roof biodiversity and habitat value. In addition, a greater diversity of flora will in general support greater faunal diversity.

PricewaterhouseCoopers (2010) **discusses business risks related to biodiversity including direct impacts or dependencies on biodiversity and ecosystem services; also regulatory, financing, reputational and supply chain risks that arise due to business's relationships with biodiversity and ecosystems**.

- Encourages companies to explore sustainable practices which promote the preservation of biodiversity and ecosystem services to reduce risk of resource/economic loss in the future.
- The total annual economic cost of biodiversity loss and ecosystem degradation was estimated to be between US$2 and US$4.5 trillion14 in 2008 (3.3 – 7.5% of global GDP). *TEEB Cost of Policy Inaction Study, (2008).*
- <u>Example Case Study</u>: In the 1990's, Vittel (Nestlé Waters) decided to address groundwater contamination from local agricultural nitrates by compensating farmers and helping them to convert to more sustainable practices. In the first seven years Vittel spent US$32m on this program. While this is a considerable cost, it is small relative to the cost of plant closures, relocation, or brand damage which occurred with several competing brands (Perrot-Maitre 2006).

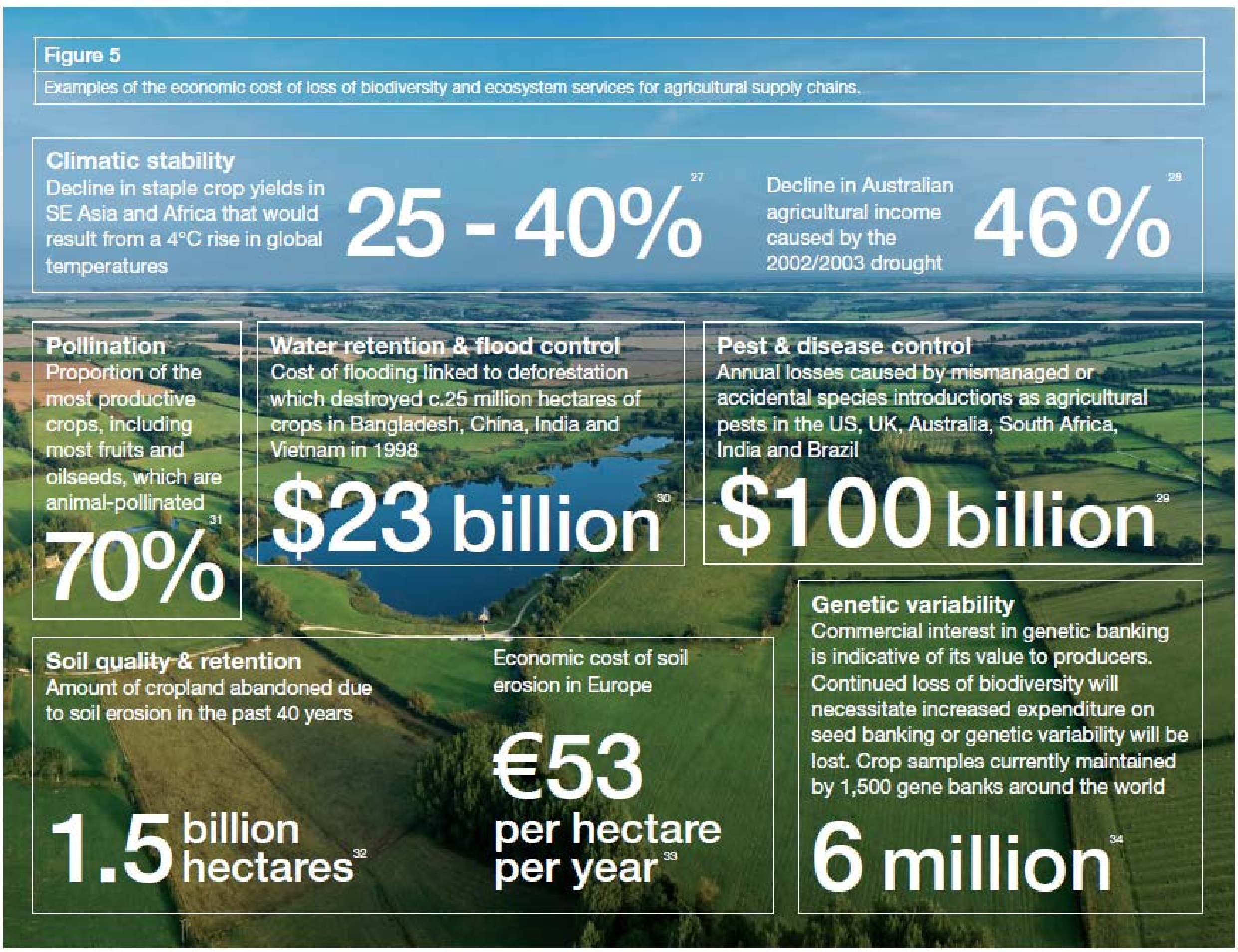

Figure 2 Examples of Costs Attributed to Loss of Biodiversity and Ecosystem Services (PricewaterhouseCoopers 2010)

Seigel et al. (2005) conducted a case study of tidal-marsh restoration and avian response in Hackensack Meadowlands, NJ.

- The use of tidal-marsh restoration has increased in response to the continued degradation of wetlands and an enhanced understanding of the value of wetlands in urban areas
- Birds may be particularly good indicators of habitat quality because they integrate multiple environmental influences in a habitat and respond quickly to changes in habitat (Neckles et al., 2002; U.S. Environmental Protection Agency, 2002).
- Through the addition of open water and other habitats during restoration, Shannon diversity of habitat types at Harrier Meadow increased from 0.965 in 1997 to 1.121 in 2002. A total of 43 bird species were observed in the marsh in 1997. In comparison, cumulative species richness in 2002 was 57, an increase of more than 30% after restoration.
- Changes to the elements of diversity—species richness and evenness—were more indicative of the influence of restoration. On a per-survey basis, pre-restoration species richness was approximately half that of post-restoration.
- Restoration of Harrier Meadow increased habitat heterogeneity considerably, including a large increase in open-water habitat. Avian community structure also changed considerably. The most prominent changes included a significant increase in avian abundance and an accompanying transition from a community dominated by passerines to one dominated by waterbirds.
- With tidal influence restored and new ponds created, there was a greater area of surface water in the marsh, and the availability of water was more persistent throughout the year. As a result, avian species that relied on water for various activities, including foraging, were consistently present in the restored marsh, whereas they were occasional visitors in pre-restoration surveys.
- It appears that the restorations at Harrier and Mill Creek were successful because each newly created habitat was associated with increased avian use.

Improved Water Quality from LID Practices

Beattie (2009) **describes studies of evaporation and evapotranspiration of water from green roofs; also examines buffer potential.**

- Certain media types in green roofs have been shown to neutralize acid rain and absorb other pollutants such as heavy metals; green roofs have also been used as alternative habitat for wildlife
- A test method to quantify acid rain buffering capacity for green roof media was developed and evaluated with two commercial media. The data suggest that common commercial media can neutralize acid rain for 10-30 years depending on acid deposition rates and amounts of lime added to green roof media to raise pH
- Green roofs may contribute small amounts of metals to stormwater

Bedan and Clausen (2009) **developed a comparison study of stormwater runoff quality/quantity from traditional vs. LID practices**.

- LID reduced export of pollutants including nutrients and metals when compared with traditional development
- Mean weekly storm flow increased (600x) from the traditional watershed in the postconstruction period.
- Increased exports of TKN, NO3 + NO2-N, NH3-N, TP, Cu, Zn, and TSS in runoff were associated with the increased storm flow.
- Postconstruction storm flow in the LID watershed was reduced by 42% while peak discharge did not change from preconstruction conditions.
- Exports were reduced from the LID watershed for NH3-N, TKN, Pb, and Zn, while TSS and TP exports increased which was attributed to grassed swales

Berke et al. (2003) **compared integration of watershed protection into new urban (LID) vs. conventional development.**

- New urban designs use less land area and have less impervious surfaces to decrease runoff; have the same level of BMP implementation as traditional development
- New urban developments are more effective in incorporating watershed protection techniques than conventional developments
- A higher percentage of new urban developments protect hydrologically sensitive areas such as natural drainage depressions, stream buffers, and steep slopes that have significant impact on mitigating adverse impacts of urbanization on receiving waters.

Berndtsson et al. **(2006) performed a study to determine whether vegetated roofs are a source or sink for runoff pollutants. (Sweden).**

- Vegetative roofs did not provide rainwater treatment; with the exception of N, vegetative roofs act as a source of runoff contaminants (P and some metals) due to use of fertilizers
- Most of the studied vegetated roofs contribute phosphate phosphorus to the runoff except the oldest roof
- Vegetated roofs had a minor influence on the metal content of the runoff
- The reduced annual loads in runoff vs. precipitation load of Cr, Mn, and Zn are likely due to the reduction in runoff volume (by the roof)
- While vegetated roofs in Augustenborg retained lead deposited in precipitation, the older roof at the Gunnesbo School behaved as a source of lead.
- The simulation study showed that when the concentrations of zinc and copper in the applied water are greater than in rain water, vegetated roofs behave as a sink retaining a large percentage of these pollutants.

Anderson et al. (2008) **present information gained from a case study on the Rock Creek Sustainability Initiative in Oregon.**

- LID practices such as rain gardens, wetlands, green roofs, and porous paving help improve downstream water quality through runoff treatment
- The lower price of the conventional scenario is accompanied by a low level of related hydrologic services and a high likelihood of incurring higher costs from higher landscaping, salmon habitat restoration, and higher water purification and drinking water acquisition costs.
- The moderately higher price of the LID-lite scenario is accompanied by a somewhat reduced likelihood of incurring these additional costs, as well as a moderately higher level of hydrologic services stemming from its increased filtration rates.
- The LID-complete scenario has the highest costs, but the possibility of avoiding the additional costs outlined above is greatly reduced in large part due to the resulting high level of hydrologic services, but also because of the lower future landscaping costs that also accompany the scenario.
    - The LID scenario will help protect salmon and salmon habitat. One study (ODFW, 2003) calculated the value of the 400 salmonids that pass through the Rock Creek area at $872 apiece. Based on this information, the LID scenario will help protect a salmon population valued at $174,000. The LID scenario also helps protect salmon habitat and avoids future restoration costs.

Brattebo and Booth (2003) **examined the long-term effectiveness of permeable pavement as an alternative parking lot surface.**

- Permeable pavement is durable and almost completely reduces runoff; runoff also had lower levels of heavy metals, motor oil and fuel deposits; may be a good management tool when site conditions are considered
- The infiltrated water from 4 commercially available permeable pavements had significantly lower levels of copper and zinc than the direct surface runoff from the asphalt area.
- Motor oil was detected in 89% of samples from the asphalt runoff but not in any water sample infiltrated through the permeable pavement.
- Neither lead nor diesel fuel were detected in any sample.
- All samples from asphalt runoff exceeded Washington State surface water-quality standards for copper at both acute and chronic toxicity levels
- In contrast, 72% (copper) and 22% (zinc) of the infiltrated water samples from the permeable systems were below the minimum detection limit

Abolt and Newport (2008) **developed a case study describing Aurora, IL's Rooftops to Rivers Plan to use green infrastructure to restore the Fox River Watershed.**

- The City is investing more than $50,000,000 towards separating stormwater and sanitary sewers to alleviate CSOs and prevent sewer backups in residents’ homes; Part of Illinois' $20 million riverfront redevelopment initiative

- The integrated use of vegetated swales, filter strips and rain gardens—shallow, landscaped depressions used to promote absorption and infiltration of stormwater—can reduce runoff and improve water quality
    - Improved water quality and reduction of nonpoint source pollution deposition
- Installing riparian buffers that include trees along Indian Creek and the Indian Creek tributary will improve water quality, reduce stormwater runoff and provide habitat for urban wildlife
    - Urban wildlife habitat creation through naturalized stormwater management and interconnected greenways - when vegetated with native plants, these buffers also can create natural habitat corridors for urban wildlife.
    - Community education regarding the value of BMP implementation
    - Provide a model for naturalized stormwater management for the region and the Fox River Watershed

Modeling analysis shows that LID can provide similar or better CSO abatement compared to traditional storage tanks for similar costs, and cost-effectiveness can be optimized through a combination of LID and traditional techniques. Brooklyn, NY. Monalto et al. 2007

- Compared the cost-effectiveness of different combinations of LID treatment (green roofs, porous pavement, and a treatment wetland) and conventional storage tanks to reduce the incidence of CSOs.
- Used low impact development rapid assessment (LIDRA), which uses hydrological and cost accounting methods applied to specific LID systems that can be incrementally installed across a landscape. The rational method was used to determine the potential reduction in CSOs. Life cycle analysis was used to determine costs over a 36-year period.
- Concluded that under a range of cost and performance assumptions, LID systems could potentially achieve cost effective reductions in CSOs at costs that are competitive or better than CSO tanks.
- The case study suggests that LID programs are best implemented and most effective in the context of integrated watershed planning efforts that involve public agencies working with private property owners.

Management practices that address the amount and connectedness of impervious surface and the amount of tree cover watershed-wide and in the riparian area would be influential in determining stream health. Montgomery County, MD. Snyder et al. 2005

- Used satellite-derived land use imagery and stepwise logistic regression models to identify landscape/land use factors accounting for the most variation in stream health ranking.
- The most influential variables determining stream health were the percent ISA, followed by the percent of tree cover and riparian buffer zone tree cover. Regarding spatial configuration of impervious cover, a contagion index and the percent of ISA in the flow path from the ISA to the stream were also found to be significant predictors of stream health.

- The results indicate that management practices designed to improve stream water quality should focus on the amount of ISA and tree cover in both the watershed and within the buffer zone.

Roseen et al. (2010) **report on wet-weather flow monitoring of stormwater treatment systems on a construction site at 3 phases**.

- Porous asphalt, green areas, gravel wetland, stormwater management systems are operating well and providing a high level of water quality treatment for the runoff from a high contaminant load commercial site and provide significant protection to the impaired receiving waters of Pickering Brook.
- Water quality results indicate that effluent pollutant levels as they leave the site at the gravel wetland are typically at or below ambient stream concentrations across a wide range of contaminants.

Improved Water Quality from Stream Restoration

Collins et al. (2004) **used multi-attribute, choice experiments and nested logic models to derive the economic values of full restoration of Deckers Creek, West Virginia.**

- Acid mine drainage (AMD), primarily from abandoned mine lands, alone degrades almost 90% of the over 5000 stream miles that are impacted by acidification. Problems associated with AMD are the contamination of public drinking water and industrial water supplies, disrupted growth and reproduction of aquatic plants and animals, decline in valued recreational fish species such as trout, restricted stream use for recreation, and corroding effects on parts of infrastructure on bridges. This study uses survey methods to determine the value of restoration of Deckers creek which is severely degraded due to acid mine drainage.
- Respondents had the highest value for aquatic life when fully restoring Deckers Creek to a sustainable fishery rather than "put and take" fishery that cannot sustain a fish population
- This higher value for aquatic life implied that respondents had stronger preferences for full restoration of this attribute than the scenic quality and fishing.
- The consumer surplus estimates for full restoration of all three attributes ranged between $12 and $16 per month per household. Potential stream users (anglers) had the largest consumer surplus gain from restoration while non-angler respondents had the lowest.
- When the welfare estimates were aggregated up to the entire watershed population, the benefit from restoration of Deckers Creek was estimated to be about $1.9 million annually with only an estimated 1/3 of households placing a positive value on restoration.

Davis et al. (2003) **summarize pre-restoration data collected from an urban stream restoration project in Gypsum Creek in Wichita, Kansas.**

- Findings show that stream degradation resulting from urbanization significantly affect biological communities, species diversity, and overall health of aquatic organisms

- Low gradient streams like Gypsum Creek typically meander more and subsequently have higher sinuosity values resulting in more complex habitat conditions. Sinuosity values were extremely low, demonstrating the extent of channelization of the stream. With virtually no meander present in the channel, little diversity in channel morphology was present. Channel morphology at all sites was >75% pool habitat.
- Available in-stream cover was limited to a few areas of undercut banks, overhanging vegetation, and filamentous algae. Reduced complexity of fish cover within urban streams can be devastating to aquatic communities. Absence of these structures limits breeding areas and offers little protection from predators; reduction in sediment complexity can also have adverse effects on breeding
- Fish communities also showed signs of stress due to toxicity of pollutants in runoff including pesticides

Browning (2010) **presents a case study for a "Seepage Wetland" design approach to stream restoration for urban stormwater management in Wilelinor Stream Watershed in Maryland.**

- The total cost of the 1,311 foot stream restoration project was $1.02 million (adjusted to 2008 dollars), which is $776/foot.
- The "seepage wetland" design approach restores the most ecosystem services for a reasonable cost per linear foot, relative to hard and soft stream restoration approaches.
- Restoration features such as seepage reservoirs and off-line ponds offer opportunities for groundwater recharge, freshwater storage, wetland creation, and valuable aquatic habitat.
- Addition of woody debris and other vegetation, such as those found along the sand berms at Wilelinor, may have the potential to improve soil carbon levels, create benthic habitat, and enhance nitrogen removal and stream bank stability.
- The average difference between upstream and downstream concentrations of nitrate-N was 0.17 mg/L, resulting in a 39% overall removal efficiency of nitrate-N.
- Average total suspended solids was 13.49 mg/L at the upstream monitoring location and 9.35 mg/L at the downstream monitoring location
- Average dissolved oxygen was 7.37 mg/L at the upstream monitoring location and 8.70 mg/L at the downstream monitoring location, resulting in an average difference of 0.93 mg/L

Improved Water Quality from Pollutant Removal

Allison et al. (1997) **conducted a case study on the CRC monitoring program for gross pollutants/litter in stormwater. (Australia)**

- Gross pollutants and litter in stormwater can pose threats to human health wildlife and aquatic habitats. This study shows the benefits of various litter trapping devices on downstream water quality/habitats.
- Results from the CRC monitoring program suggest that urban areas contribute about 20-40 kilograms (dry mass) per hectare per year of gross pollutants to stormwater. For Melbourne, this is equivalent to approximately 60,000 tons or 230,000 cubic meters of gross pollutants and about 2 billion items of litter annually (about one item per person per day).
- The composition of gross pollutants during events remains relatively constant compared to the concentration and load fluctuations
- Gross pollutant concentrations are highest during the early stages of runoff, but most of the load is transported during times of high discharge

- The loads and concentrations of gross pollutants generated by a storm are similar to those generated by other storms occurring earlier on the same day.
- Gross pollutant trapping devices can be very effective in removing gross pollutants from stormwater runoff; several types tested showed between 80-100% removal efficiency

Beasley and Kneale (2002) **conducted a study on the impacts of metals and PAHs on invertebrates; more research is recommended.**

- Pollution from sediments in urban surface waters impairs water quality and aquatic habitat (metals and PAHs)
- Results from the field study show the quality of streambed sediments is impaired generally and demonstrate the importance of looking at both metal and oil contaminants together.
- Sites below inputs collecting runoff from housing or roads all show reduced macroinvertebrate numbers. Heavy metals and PAHs are elevated in most sediments compared with the natural, pristine control sites
- More research is needed in order to determine the specific effects of each contaminant and their overall combined impacts on various aquatic systems

Bjorklund et al. (2009) **studied the occurrence, distribution, and area emission factors of phthalates and nonylphenols in urban runoff. (Sweden)**

- Phthalates and nonylphenols (additives in plastics and detergents) were found in most urban waterways in Sweden in various concentrations in both aqueous samples and sediment; these compounds are known to have endocrine disrupting effects and are toxic to aquatic organisms; implications for stormwater treatment/sedimentation control

Campbell (1994) **conducted a case study and field sampling to look at the concentrations of heavy metals in fish living in SW treatment ponds in Orlando, Florida**.

- Fish living in SW ponds were found to have significant levels of heavy metals, likely influenced by sediments
- Redear sunfish from stormwater ponds contained significantly higher ($p < 0.005$) concentrations of cadmium, nickel, copper, lead, and zinc than redear from controls.
- Largemouth bass collected from stormwater ponds contained significantly higher ($p < 0.005$) concentrations of cadmium and zinc than those from control sites.
- Bluegill from stormwater ponds contained significant copper concentrations ($p < 0.005$) as compared to bluegill from control sites.
- While these ponds reduce runoff the fish in them can be a contaminated food source for other wildlife; further studies should be conducted to determine the impacts of heavy metals and bioaccumulation in wading birds and other predators

The California Regional Water Quality Control Board (2001) **developed a trash TMDL for the Los Angeles River which contains an assessment of trash in the River and a detailed description of TMDL targets and BMPs. Contains monetized values of SW treatment devices and of trash clean-up costs.**

- Trash in waterways causes significant water quality problems. Small and large floatables can inhibit the growth of aquatic vegetation, decreasing spawning areas and habitats for fish and other living organisms. Wildlife living in rivers and in riparian areas can be harmed by ingesting or becoming entangled in floating trash.
- Approximately 1,620 tons of litter are estimated to be discharged to the Los Angeles River annually, requiring costly removal measures.
    - The Los Angeles County Department of Public Works contracts out the cleaning of over 75,000 catchments (catch basins) for a total cost of slightly over $1 million per year, billed to 42 municipalities.
    - Over 4,000 tons of trash are collected from Los Angeles County beaches annually, at a cost of $3.6 million to Santa Monica Bay communities in fiscal year 1988-89 alone. In 1994 the annual cost to clean the 31 miles of beaches (19 beaches) along Los Angeles County was $4,157,388.
- Storm drains are the major source of trash in the Los Angeles River; The TMDL assigns wasteload allocations and sets up implementation strategies; these include source monitoring, end of pipe capture control structures and other BMPs
- The numeric target for trash is zero or no trash in the water
- Implementation of the TMDL and BMPs could save money on long term trash clean-up costs; high costs are associated with watershed/beach cleanups.

Hathaway et al. (2009) **conducted a study in Charlotte, N.C., monitoring nine storm-water BMPs (one wet pond, two storm-water wetlands, two dry detention basins, one bioretention area, and three proprietary devices) for fecal coliform and E. coli.**

- The wet pond, two wetlands, a bioretention area, and a proprietary device all removed fecal coliform with efficiency higher than 50%; however, only the wetlands and bioretention area had significantly different influent and effluent concentrations.
- Sun exposure (UV light penetration) possibly led to increased inactivation of indicator bacteria in the wetland in between storm events and during the slow drawdown after an event
- For E. coli, only one of the wetlands and the bioretention area provided a concentration reduction greater than 50%, both of which had a significant difference in influent and effluent concentrations.
- Only one of the nine BMPs had a geometric mean effluent concentration of fecal coliform lower than the U.S. EPA target value
- Four of the nine BMPs had geometric mean effluent concentrations lower than the U.S. EPA standard for E. coli.

Foster and Lippa (1996) **sampled three tributaries to the Chesapeake Bay during base and storm flow conditions monitoring for surface water concentrations of organo-N/P pesticides.**

- Annual loads of the organo-N/P pesticides were directly correlated with field application rates and stream discharge; the influxes of pesticides and other organic contaminants contributed by the tributaries are being compared with identified nonpoint sources in Chesapeake Bay.
- Results indicate that biota in the Chesapeake Bay are exposed to long-term low-level concentrations of pesticides. There are currently no clear implications of cause and effect that may be drawn between the estimated annual loads and the health of the Chesapeake Bay.

Boller (1997) **studied deficits of urban drainage systems; includes case studies.**

- Stormwater runoff from roofs and streets contribute 50-80% of heavy metals found in combined sewers; in separate sewers levels are even higher; stormwater infiltration using adsorbent materials may help reduce transport of metals downstream

Bannerman et al. (1993) **present results from a case study of field sampling in Madison WI, and modeling for runoff volumes.**

- Critical sources of pollutants in runoff areas are identified in order to target most important sources and reduce area for BMP placement; used SLAMM urban runoff model
- Streets are critical source areas for most contaminants in all the land uses. Parking Lots are critical in the commercial and industrial land uses. Lawns and driveways contribute large phosphorus loads in the residential land use. Roofs produce significant zinc loads in the commercial and industrial land uses
- Identification of critical source areas could reduce the amount of area needing best-management practices in two areas of Madison, WI. Targeting best-management practices to 14% of the residential area and 40% of the industrial area could significantly reduce contaminant loads by up to 75%.

Alexander et al. (2007) **use water quality modeling (SPARROW model) to determine effects of headwater streams on downstream water quality including transport and transformation of nutrients**

- Headwaters have major impacts on downstream water quality; runoff and land use changes may increase impacts of pollutants and nutrients such as N
- Findings show that first-order headwaters contribute approximately 70% of the mean-annual water volume and 65% of the nitrogen flux in second-order streams. Their contributions to mean water volume and nitrogen flux decline only marginally to about 55% and 40% in fourth- and higher-order rivers that include navigable waters and their tributaries.
- Increases in the peak discharge and flashiness of flows that are often associated with urbanization would be likely to reduce the natural processing of nitrogen in low-order streams, increasing the distance over which nitrogen is transported downstream

- Atmospheric deposition is the largest source of nitrogen in headwater catchments, accounting for nearly 70% of the total incremental load delivered to headwater streams, with cultivated land and urban/ suburban sources accounting for about 27% of the incremental load

Stormwater Management for Aquatic Ecosystem Health/Biological Integrity

Horner et al. (1999) **tested whether the use of structural and nonstructural stormwater BMPs will allow a healthier biological community at higher levels of imperviousness.**

- Retention of a wide, nearly continuous riparian buffer in native vegetation has greater and more flexible potential than other options to uphold biological integrity when development increases
- Upland forest retention also offers valuable benefits, especially in managing any development occurring in previously undeveloped or lightly developed watersheds
- Structural BMPs have less mitigation potential than the non-structural BMPs assessed
- Structural BMPs appear to have the realistic potential to mitigate only about 5% total impervious area increase
- The most effective non-structural BMPs retain natural soil and vegetation cover, which in the Puget Sound region means the forest that covers undisturbed landscapes.
- Intact upland forest and riparian zones in forest cover or wetlands were regarded as effective non-structural BMPs
- The findings were reviewed to propose a set of conditions that appear to be necessary, though not by themselves sufficient, for a high level of biological functioning (Puget Sound area). These include:

    - 1. >70 percent of upstream riparian zone in forest cover or wetlands >30 meters wide,
    - 2. 2-year peak flow rate/winter baseflow rate <20,
    - 3. <15 percent of surface bed material composed of fine sediments (<0.85 mm),
    - 4. pebble count DIO >5 mm,
    - 5. Intragravel DO/DO >0.8,
    - 6. Large woody debris frequency >2 per bankfull width (BFW).
    - 7. >40 percent of large woody debris with diameter >0.5 meter,
    - 8. >50 percent of surface area in pool habitat.
    - 9. < 2 BFWs between pools
    - 10. >50 percent cover over pools

Castelle et al. (1994) **conducted a literature review to determine wetland and stream buffer size requirements to maintain and protect aquatic environments.**

- Based on existing literature, buffers necessary to protect wetlands and streams should be a minimum of 15 to 30 m in width under most circumstances.
- Isolated wetlands, riparian corridors, and their buffers often afford most of the green space in urban environments. These green spaces allow animals and birds to travel through the urban landscape with some protection from humans and domestic animals in wildlife corridors.
- Milligan (1985) studied bird species distribution in 23 urban wetlands in King County, Washington. Bird species diversity, richness, relative abundance, and breeding numbers were positively correlated with wetland buffer size.
- Moring (1982) assessed the effect of sedimentation following logging with and without buffer strips of 30 m (98 feet) and found that increased sedimentation from logged, unbuffered stream banks clogged gravel

streambeds and interfered with salmonid egg development. With buffer strips of 30 m or greater, salmonid eggs and alevins developed normally.

Fitzpatrick et al. (2004) **examined 43 streams for trends in biotic integrity, sediment chemistry, and urbanization along a gradient from agricultural to urban near Chicago, Illinois.**

- The Illinois fish Alternative Index of Biotic Integrity (AIBI) ranged from poor to excellent in agricultural/rural streams, but streams with more than 10 percent watershed urban land (about 500 people/square mile) had fair or poor index scores. Streams with greater than 40 percent urban land or about 1,600 people/mi2 generally had poor AIBI scores
- A macroinvertebrate index (MBI) showed similar trends.
- Elevated copper concentrations in sediment occurred in streams with greater than 40 percent watershed urban land.
- The number of intolerant fish species and modified index of biotic integrity scores increased in some rural, urbanizing, and urban streams from the 1980s to 1990s, with the largest increases occurring in rural streams with loamy/sandy surficial deposits
- In general, fish and macroinvertebrate indices of biotic integrity decrease as agricultural land is replaced by urban land.
- Overall, Initial decreases in biotic integrity scores occur at about 10 percent watershed urban land and 500 people/square mile. Further decreases occur at about 45 percent watershed urban land and are correlated to concentrations of urban-related trace elements such as chromium, copper, and nickel.

Gray (2004**) studied short term changes in water quality and long term changes in substrates and macroinvertebrates from urban runoff. (Provo, Utah)**

- Data from 4 sites show that impervious surface cover in the lower Provo River has increased from 17% to 49% of total area in the past 15–25 years
- As a result, stormflows had increased TSS, dissolved copper, lead and zinc, and decreased conductivity and DO; changes were temporary with water quality parameters returning to pre-storm levels within 12 hours.
- River substrates showed increased compaction and decreased debris.
- Macroinvertebrate communities decreased abundance and species diversity with increased urbanization
- Species diversity significantly declined downstream due to a loss of sensitive taxa; compared to non-urban reaches, communities in urban reaches had few sensitive species and were dominated by tolerant species, particularly snails and leeches
- Changes in water quality resulting from urban storm runoff do not appear to have a significant effect in causing differences between upstream and downstream benthic communities.
- Changes in the characteristics of the river substrates between upstream and downstream reaches are a more likely cause for at least some of the changes in community structure.
    - The increased compaction of substrates at the downstream sites effectively reduces the total habitat volume available for macroinvertebrates

Stream sites showed better biological condition if flows to the site were controlled by stormwater management facilities unless drainage area imperviousness exceeded 23%. Montgomery County, MD. Montgomery DEP undated

- Assess the ability of stormwater management controls to mitigate impacts of watershed development on the ecological integrity of first and second order non-tidal streams in the piedmont ecoregion
- Evaluated physical characteristics of stream reaches and drainage areas and grouped them according to whether they were subject to controlled (within 100 m downstream of a stormwater management facility, which is estimated to account for 95% of the stormwater reaching the site) or uncontrolled stormwater runoff.
- Concluded that biological condition declined as imperviousness levels increased, but the decline was not as steep or rapid in the sites with stormwater management controls. These controls appear to mitigate the impacts of increased imperviousness within the 12 to 23% imperviousness range. Above this level, biological condition declines at similar rates with or without controls.

Study of diatom indices indicates that connected impervious area is more influential in determining biological health than total imperviousness. Melbourne, Australia. Newall and Walsh 2005

- Compares the impacts of urbanization on stream benthic diatom communities in first- and second-order streams
- Used multivariate and univariate analyses to evaluate relationships between the physical elements of urbanization, water quality and diatom communities and species.
- Found a strong negative correlation between urban density and the diatom indices of water quality. More salt-tolerant diatom communities dominated urban-influenced streams.
- Drainage connection was the most influential variable related to decline in the diatom community (by delivering more total phosphorus to stream systems).
- Suggests that reducing directly piped drainage connection using infiltration and retention may be a more effective approach to reducing stream impacts than reducing total imperviousness.

Modeling study shows that application of urban BMPs can improve endangered mussel populations by reducing TSS and peak flows; further improvements are expected with BMPs that reduce runoff quantity. Central Massachusetts. Randihir and Hawes 2009

- Empirically modeled the effect of application of BMPs to urban land uses assuming 25% sediment removal efficiency; modeled runoff, stream flow, sediment load, and dwarf wedge mussel (an endangered species) populations.
- The reduction in magnitude and frequency of peak flows resulting from urban BMPs improved the recovery of dwarf wedge mussel populations.
- To reduce the impact of high density land use on the mussel population, BMPs that decrease the quantity of runoff water should be applied using a prioritization approach.

Forested riparian buffers can be protective of fish assemblages at low levels of urbanization but their protective effect is not sufficient in highly urbanized areas. North-central Georgia. Roy et al. 2007

- Modeling study to assess the influence of land cover at multiple spatial extents on fish assemblage integrity, and the degree to which riparian forests can mitigate the negative effects of catchment urbanization on stream fish assemblages.
- Found that at low levels of urbanization (< 15%), riparian forests can moderate upland disturbances and help to maintain fish assemblage integrity.
- Forested riparian buffers may not be sufficient for protecting fish assemblages in highly urbanized areas.
- Efforts to enforce stricter buffer regulations on future developments to restrict loss of forest in the 30-m buffer along stream networks would offer the best protection of stream fishes only if associated with regional planning to minimize catchment-scale disturbances.

The amount of connected impervious surface area was the most significant predictor of fish community health and baseflow, and policies to reduce such area, particularly in stream buffers, could reduce the impacts of urbanization on fish communities. Southeastern Wisconsin. Wang et al. 2001

- Used nonlinear regression to analyze the amount and spatial pattern of land cover in relation to stream fish communities, instream habitat, and baseflow.
- The amount of connected impervious surface in the watershed was the best measure of urbanization for predicting fish density, species richness, diversity, and index of biotic integrity score; bank erosion; and base flow. Connected imperviousness was not significantly correlated with overall habitat quality for fish.
- Connected imperviousness levels between 8 and 12% represented a threshold region where minor changes in urbanization could result in major changes in stream condition.
- Connected imperviousness within a 50-m buffer along the stream or within a 1.6-km radius upstream of the sampling site had more influence on stream fish and base flow than did comparable amounts of imperviousness further away.
- BMPs and policies that minimize the amount of connected impervious surface and establish undeveloped buffer areas along streams should reduce development impacts.

Stream temperature and urban land use, particularly in riparian areas, influenced macroinvertebrate community health. Wisconsin and Minnesota. Wang et al. 2003

- Multivariate analysis of riffle and snag habitats in small cold water streams to evaluate the influences of urban land use and in-stream habitat on macroinvertebrate communities.
- Stream temperature and amount of urban land use in the watersheds were the most influential factors determining macroinvertebrate assemblages.
- Watershed urbanization was negatively correlated with percentage of EPT abundance, EPT taxa, filterers, and scrapers and positively correlated with Hilsenhoff biotic index.
- Threshold beyond which index values tended to be poor was 7% effective imperviousness.

- Land uses in the riparian area were equal or more influential relative to land use elsewhere in the watershed.
- Emphasized the importance of BMPs that restrict watershed impervious land use, protect stream riparian areas, and maintain a natural thermal regime.

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